International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Determination of Weathered Layers Characteristics of Field-K, Western Niger Delta, Nigeria Using Uphole Refraction (Borehole) Survey Technique

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Abstract: ***An up-hole survey was carried out on Field-K in Western Niger delta basin to determine some major characteristic of the weathered layers, namely the velocity, thickness, depth to interface of the weathered layers in the study area. A total of 37 up-hole refraction shots were taken and from the data recorded, a time versus depth curves for each of the up-hole location was obtained which was used to calculate the velocities of the weathered layers. Similarly, up-hole survey time versus depth curves were derived which was used in the determination of the thickness of the weathered layer. From the obtained results, the computed weathered (unconsolidated) layer seismic velocity of the study area ranges from as low as 210m/s at UPH-4 location of the study area to as high as 593m/s in UPH-29. The average weathering (unconsolidated) layer velocity over the entire area was found to be 360m/s. The thickness of the weathered layer ranged from as low as 3.1m around UPH-21 andUPH-28 locations of the study area to as thick as 6.8m around UPH-12, while the average thickness obtained for the weathered layers was 4.7m. For the consolidated layers, the seismic velocities obtained ranged from 1131m/s at UPH-32 to as high as 1987m/s at UPH-3 and the overall average consolidated layer velocity was 1707m/s. It was observed that these consolidated layers across the study area were sufficiently competent for civil engineering applications judging from their recorded high seismic velocity values. The depth to the interface (Z) ranges from 0.45m around UPH-28 of the study area to 1.50m around UPH-33. The result obtained from the study gave an overview of the lateral variations in the velocity and thickness of subsurface materials around the area of study. The results shows that the velocities of the weathering layers can be easily and accurately determined using the uphole survey compared to the downhole survey with some level of uncertainties.***

Keywords: Weathering Layer, Uphole Survey, Refraction, Consolidated, Unconsolidated, Velocity, Thickness, Elevation, Travel Time

1. Introduction

An up-hole seismic refraction survey is a technique which is often used to determine velocities of weathered layers of the subsurface. It entails propagating seismic waves from sources around a borehole and recording the arrival times of refracted waves by surface geophones. Weathered or unconsolidated (loosed) layers of the subsurface are near surface layers of the earth crust which are characterized by the presence of loose unconsolidated or weathered sedimentary materials or an exfoliated materials of metamorphic or igneous rocks (Ofomola, 2011). These layers are known for their low seismic velocities, for this reason they are also referred to as low velocity layers (LVL). These layers often affect adversely the seismic velocity during the processing of seismic data. The weathered layers of the subsurface possess irregular thicknesses and varying low seismic velocities. This variation in velocity affects travel-times along elevation changes and is characterized by low transmission of seismic waves and generation of seismic multiples. There is a great disparity in the velocity of the weathered layer (LVL) with that of the underlying consolidated strata which could cause errors in the arrival times of reflected/refracted waves or signals associated with small changes in the thickness of the weathered layer, this variation also has a considerable influence in the processing and interpretation of deep seismic reflection/refraction data.

It is pertinent to know the thickness or depth to the base of the weathered layer before a seismic survey. The knowledge of the thickness of the weathered layer is needed as a reference guide to seismic acquisition teams toadvise them on where to locate the energy source and at the appropriate depths so as to reduce the masking effects of ground roll that will interfere with the reflected signals.The information gotten from the determination of weathered layers (LVL) goes a long way in helping seismologists during oil exploration and groundwater exploration projects and Architects in their construction works.Information derived from weathered layers could aid in proper placement of dynamites at the right depths during acquisition programs. It helps in removing the effect of topographic differences for the various shot points taken on a spread thereby aiding the processed data produce a true picture of the subsurface. It plays the role of reducing the seismic data to a specific datum (Entezari and Ramazi, 2011). Errors in acquisition through computations caused by the recording system such as convolutions and distortions due to the physical properties of reflected waves such as Normal Moveout (NMO) and Common Depth Point (CDP) stacking could be eliminated through information's derivable from of the weathered layers (Ofomola, 2011). In hydrogeological investigations, it provides direct information on the level of water table, since an increase in water content causes a significant increase of seismic velocity for a homogeneous lithology (Alhassan *et al.*,2010).

The up-hole refraction survey is a useful tool by which the thickness and velocity of the weathered layer (LVL) could be derived. Ofomala in 2011 conducted an up-hole seismic refraction survey in Yom field S-E Niger Delta for the determination of the low velocity layers (weathered layers). Five up-hole locations were occupied in his study and from the graphs plotted for each up-hole point, the velocities and the weathered layer was obtained and the depth calculated. Enikanselu in 2008 analyzed an up-hole refraction survey

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for weathered layer characteristics in the "mono" field N-W Niger Delta. Twenty nine up-hole survey points were occupied and the results obtained from his study revealed the trend and thickness of the weathered layers and their velocities as well. An up-hole seismic refraction survey for subsurface investigation was carried out in Liso field, Niger Delta (Adeoti*et al*,. 2013). From the analysis of their up-hole measurements, they were able to infer the velocities and thickness of the weathered layers.

In this study, we seek to determine the thickness or depth of the weathered layers over OPL-135 in the western part of the Niger Delta with their associated velocities from measurements obtained from thirty seven up-hole seismic refraction surveys conducted within the study location.

2. Location and Geology of the Study Area

The present field was an area in western Niger Delta where a 3D seismic survey was carried out. The survey spanned four Local Government Areas (Aniocha South, Ndokwa East, Oshimili North and Oshimili South)in Delta State, Nigeria and surrounded by Anambra, Edo and Enugu state in the North East, West and far North respectively (Figure 1).

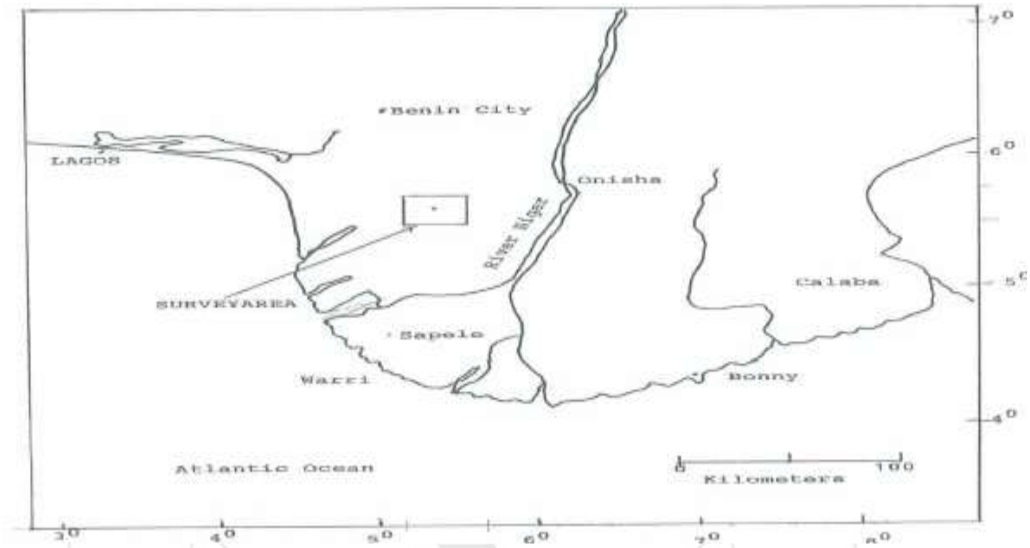

Figure 1: Map of Study area showing Niger Delta Area of Southern Nigeria

The vegetation in the study area varies from farm lands, light vegetation and grass lands in its western and central part. Plantain plantations, raffia flooded plains and tropical rain forests dominate its eastern region. The present field is subject to heavy flooding and erosion in the wet season from late July to December, also noticed, were numerous small lakes and fish ponds which are all of some economic valueto the inhabitants of the local communities who predominantly are fishermen. Access to the study area is fairly good as the major Ughelli – Asaba road runs almost centrally through the field with other minor roads linked to it. The Iyesse River runs through the central part, dividing the prospect into halves and the River Umomi, a tributary of River Niger aligns almost parallel with the field on the northern part while the River Niger bounds the prospect on the east. The area as mentioned earlier is part of the Niger Delta basin which is characterized by both marine and mixed continental depositional environments believed to have originated during the Eocene era (Asseez, 1989). Only three sedimentary formations (Figure 2) have been identified in the Niger delta, namely; the Benin, the Agbade, and Akata formations.The sediments around the field are unconsolidated and variable thicknesses throughout the region of study which comprises mainly of fresh water swamps and mangrove swamps with relief that increased towards the northern part of study area.

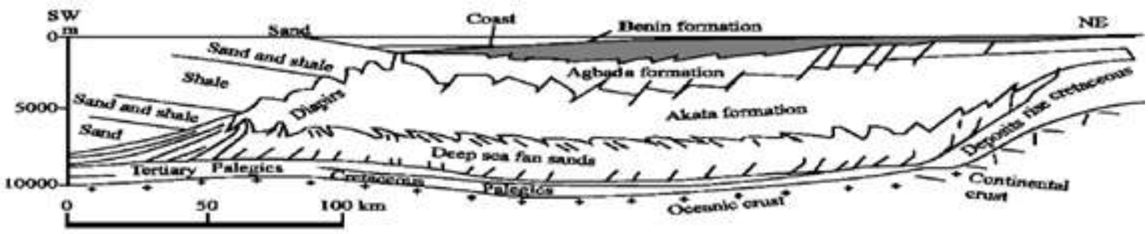

Figure 2: Stratigraphy of the Niger-Delta (After Asseez, 1989)

3. Methodology

Underlying Principle of the Up-hole Refraction Technique

After the generation of seismic wave energy during a refraction survey, the travel time (first breaks) of sound energy from a known source location through a refractor and back to a surface geophone could be determined. If a graph of first break times **T** is plotted against the offset **X** for each up-hole measurementas shown in Figure 3.The velocity of the top layer (weathered layer) is calculated from the reciprocal of the gradient of the direct arrivals, while the

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velocity of the consolidated (2^{nd}) layer (bedrock velocity) is calculated from the reciprocal of the gradient of the refracted arrivals.

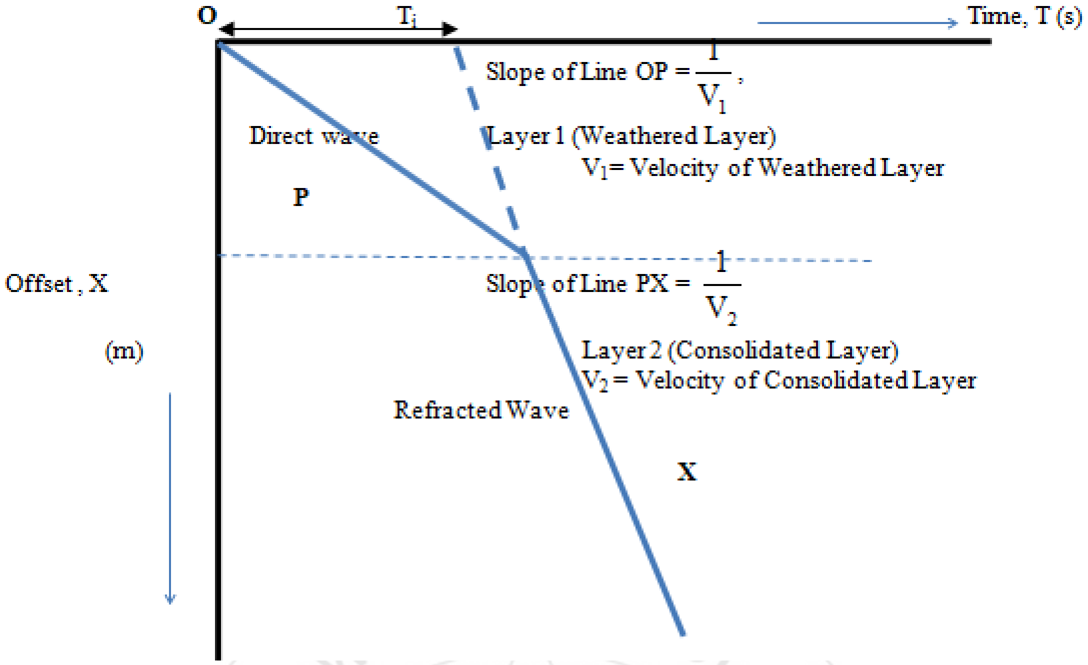

Figure 3: Plot of Travel time (T) vs Offset (X) of uphole Measurement

From figure 3 and the annotations made, the velocity of the weathered layer could easily be obtained for every up-hole point, which is the inverse of the slope of the plot. Similarly, assuming a two-layer earth model in which the energy source is located in the weathered zones, the travel time **T** is given as

$$\mathrm{T} = \frac{(\mathrm{X} - 2\mathrm{Z}\tan\theta_c + 2\mathrm{z})}{\mathrm{V}_2} + \frac{2\mathrm{Z}}{(\mathrm{V}_1\cos\theta_c)} \quad (1)$$

Where **X** is the offset distance
Θ_c is the critical angle of incident wave
Z is the depth to base of the weathered layer or depth to interface
V_1 is the weathered layer velocity
V_2 is the consolidated layer velocity

Using equation the above, and setting the offset at **X** = 0 (that is at shot point location), and from Figure 3, we can implies that travel time **T** = **T_i**, then

$$T_i = \frac{2Z}{\cos\theta_c((1/V_1) - (-\sin\theta_c/V_2))} \quad (2)$$

UsingSnell's law, which state that$\Theta_c = \sin^{-1}(V_1/V_2)$, then will can modifies equation 2above further to be

$$T_i = \frac{2Z\cos\theta_c}{V_1}$$

$$T_i = \frac{2Z\left(V_2^2 - V_1^2\right)^{1/2}}{V_2 V_1} \quad (3)$$

From the above relations, if T_i is known for all up-hole survey points, then Z which is the depth to the base of the weathered zone is obtained as

$$Z = \frac{T_i V_2 V_1}{2\left(V_2^2 - V_1^2\right)^{1/2}} \quad (4)$$

From the above equation the weathered layer thickness can be estimated, using the time depth plot. The depth to the interface is calculated from the intercept time of the refracted arrivals and the two calculated velocities and the equation to calculated depth to interface (Figure 4).

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Paper ID: ART20176950 DOI: 10.21275/ART20176950

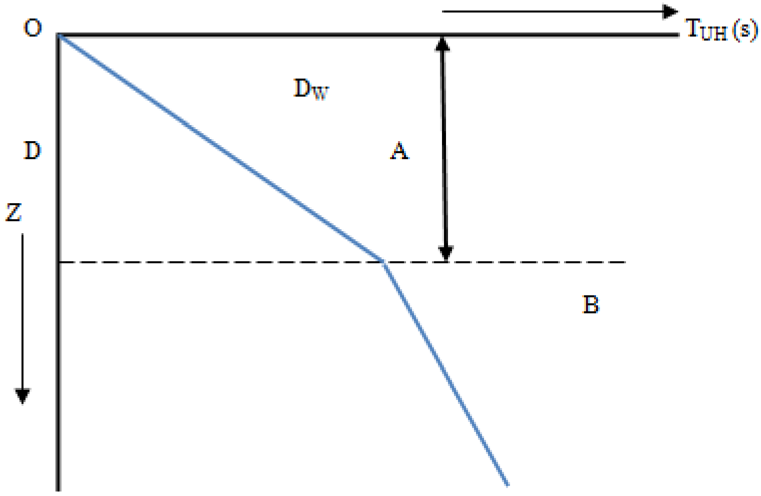

Figure 4: Plot of Uphole time (T) vs depth to Interface (Z) of weathered layer

The thickness of the weathered layer is the path covered by OA in figure 4. Therefore if the up-hole survey time versus depth graph is plotted for all survey measurements, the distances OB in each case could easily be obtained to generate the thicknesses of the weathered layers for all various survey points. The line DA (figure 4) marks the base of the low velocity layer that is the base of the weathered layer.

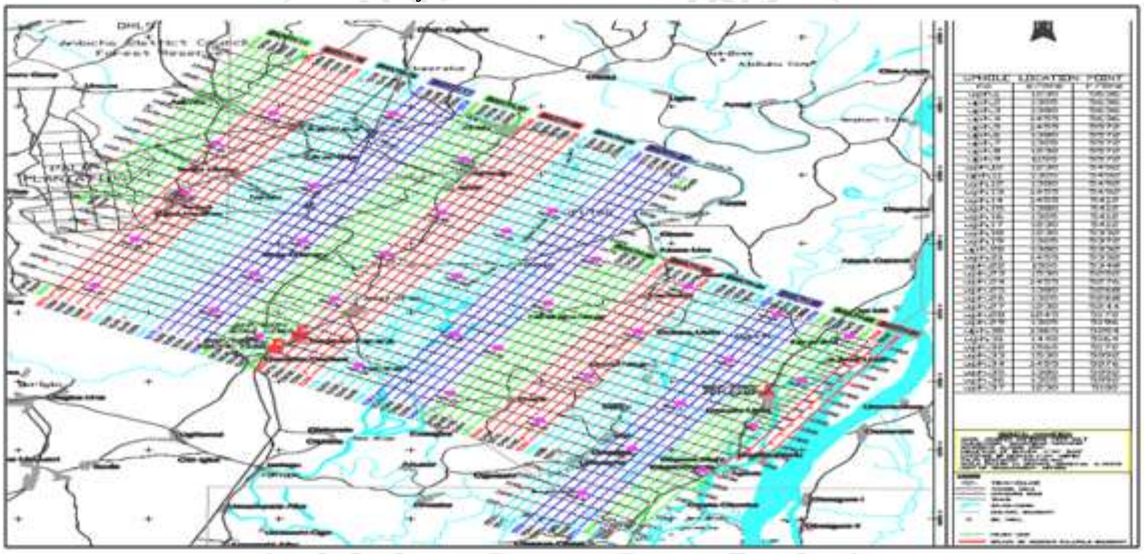

Figure 5: Up-hole survey map with up-hole points indicated with purple dots (Ref: BGP/CNPC).

For this study, a total numbers of thirty seven (37) up-hole locations in a (4.0 x 3.750) km grid specification were drilled and logged. They were all arranged such that at least four up-hole locations were taken on each swath as shown in figure 5. Up-hole data was acquired using a Geometrics stratavisor NZ11 seismograph. A schematic of the acquisition set up is shown in figure 6. A firing command was given from the blaster unit which provided the required voltage discharge needed to trigger the detonators (energy source). The blasting unit normally produces a field time signal simultaneously with the firing pulse to the caps. This signal would be fed back and recorded into the instrument to produce the arrival time sequence. Once a shot is successful the output data is documented and the harness moved to the next calibrated depth. This procedure was repeated till the last depth was logged.

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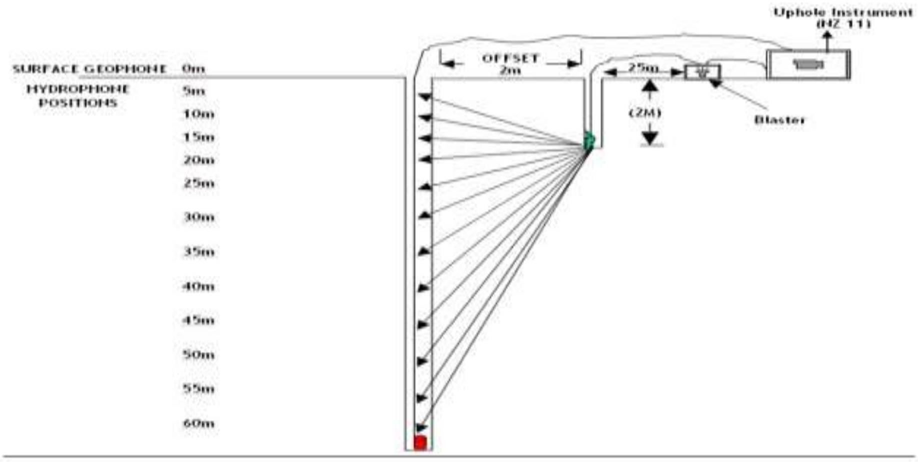

Figure 6: Up-hole refraction survey acquisition set up

The acquisition team comprised of an up-hole seismologist, an assistant, five field quality control (QC) seismologists and a licensed shooter. Material requirements for the acquisition included a recording instrument - Geometrics Strata Visor NZ11 seismograph, blaster unit, 1 hydrophone unit, a digital multimeter, marine ropes,metal weights, two 12V dry cell batteries and other consumables like survey umbrellas, firing line with connecting cables, plastic casings, plotter paper rolls, masking tapes, cutter knifes and hand napkin.

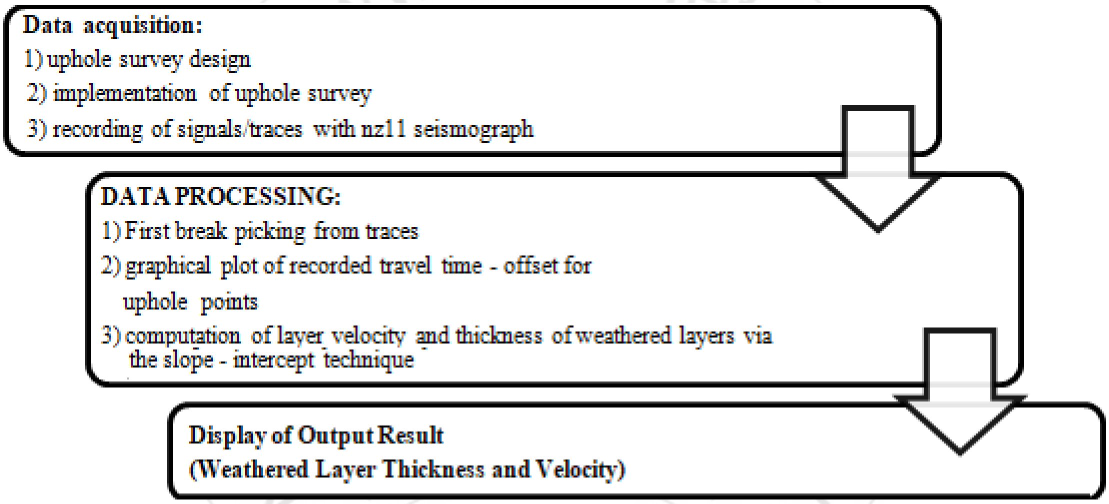

Figure 7: Block diagram showing the processing workflow adopted

The method of interpretation of the up-hole refraction survey data was by the slope/intercept method as initially discussed. A block diagram showing the workflow is presented in figure 1.6

4. Results Presentation

Measurements recorded from thirty seven (37) up-hole refraction survey locations were used for this study and the results of the subsurface parameters over the field of study is presented in table 1.0.Velocities of the weathered (**V_1**) and consolidated (**V_2**) layers were computed as well as the depth to interface (**Z**) from mathematical relations already established. The thicknesses (**OB**) of the weathered layers were also picked from the up-hole time versus depth graph plots for the 37 up-hole refraction survey locations (Table 1)

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Table 1: Results of Weathered Layer Model for the Study Area

Point No	Elevation (m)	Thickness of Weathered Layer (OB) (m)	Weathered Layer Velocities (V_1) (m/s)	Consolidated Layer Velocities (V_2) (m/s)	Time (s)	Depth To Interface (Z)(m)
UPH-1	16.60	5.2	415	1804	11	0.67
UPH-2	15.30	4.4	237	1851	17	0.55
UPH-3	15.04	4.1	261	1987	15	0.50
UPH-4	15.89	4.7	210	1810	21	0.62
UPH-5	14.86	5.0	414	1660	11	0.73
UPH-6	15.87	4.4	341	1691	12	0.63
UPH-7	15.96	5.6	384	1728	15	0.88
UPH-8	15.68	5.5	450	1711	12	0.85
UPH-9	14.50	5.3	334	1721	16	0.81
UPH-10	15.69	5.0	425	1712	11	0.73
UPH-11	15.27	4.2	316	1463	13	0.74
UPH-12	17.62	6.8	444	1967	16	0.95
UPH-13	16.67	4.7	383	1596	11	0.70
Uph-14	15.52	4.7	474	1694	09	0.68
UPH-15	14.82	4.7	452	1737	10	0.70
UPH.16	13.59	4.3	382	1712	11	0.65
UPH.17	12.91	5.0	396	1801	12	0.69
UPH.18	19.23	4.2	392	1737	10	0.59
UPH.19	14.73	4.5	336	1943	13	0.58
UPH.20	15.35	4.5	570	1690	08	0.76
UPH.21	16.35	3.1	380	1895	09	0.47
UPH.22	16.12	3.7	375	1898	11	0.57
UPH.23	16.64	3.5	539	1856	06	0.48
UPH.24	21.78	4.4	303	1914	14	0.57
UPH.25	19.82	4.2	360	1689	12	0.67
UPH.26	17.39	4.5	278	1775	16	0.64
UPH.27	18.05	3.7	540	1746	07	0.60
UPH.28	18.29	3.1	381	1778	08	0.45
UPH.29	16.36	5.0	593	1726	09	0.88
UPH.30	20.53	3.8	237	1889	15	0.48
UPH.31	44.80	5.4	301	1413	17	0.95
UPH.32	81.38	5.1	245	1131	20	1.14
UPH.33	86.21	6.7	239	1203	29	1.50
UPH.34	51.58	6.5	311	1387	21	1.24
UPH.35	47.07	4.6	209	1429	22	0.82
UPH.36	43.07	4.5	212	1482	20	0.73
UPH.37	25.76	4.0	233	1929	18	0.55

5. Discussion of Results

We observed the weathered layer seismic velocity to range from as low as 210m sec^{-1} around UPH-4 location of the study area to as high as 593m sec^{-1} around UPH-29. Thisvariation in near surface seismic velocity is indicative of the high degree of in-homogeneity of the weathered zones and underscores the possibility of a smooth static behavior in case of any seismic reflection data likely to be acquired within this zone. The weathered layer thickness ranges from as low as 3.1m around UPH-21 and 28 locations of the study area to 6.8m around UPH-12 and the average weathering thickness was determined to be about 4.7 metres. Also, the consolidated layer seismic velocity ranged from 1131m sec^{-1} around UPH-32 of the study area to as high as 1987m sec^{-1} around UPH-3. It was observed that these consolidated layers across the study area were sufficiently competent for civil engineering applications judging from their recorded high seismic velocity values. The depth to the interface (**Z**) ranges from 0.45m around UPH-28 of the study area to 1.50m around UPH-33 (Figure 8a and 8b). It could be observed that the layer is sufficiently competent judging from the seismic velocity distribution across the study area.This study has analyzed the weathering characteristics of the study area using the uphole survey techniques. The results show mainly a two layer model in almost all the interpreted low velocity layer data

The statistical analysis revealed that the weathered later was relatively heterogeneous and loose. The findings in this study have shown that any meaningful seismic reflection work in the study area required substantial static corrections, owing to the high variability of weathered layer seismic velocity and thickness. The determined depths to the base of the LVL is a vital information for the proper location of energy source for 'noise' reduction and a resultant improvement in the signal to noise ratio. . In most cases, locating the source below the LVL bypasses the layer thereby maximizing energy transmission. The information obtained from this study is extremely important in the determination of time delays needed for static corrections during seismic reflection data processing. This is because of the need to know the depth of the base of weathering layer before a seismic reflection survey, which helps to locate the energy source at appropriate depth so as to reduce the ground roll that will interfere with the seismic reflection data. Besides that, the energy transmitted into surface can be maximized by placing the source below the weathered zone.

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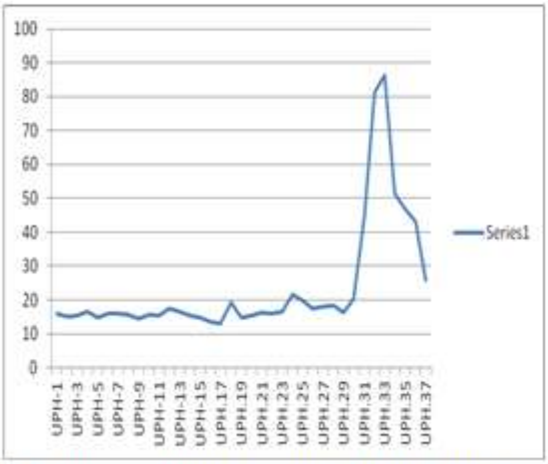

Figure 8a: Plot of Elevationvs Uphole points

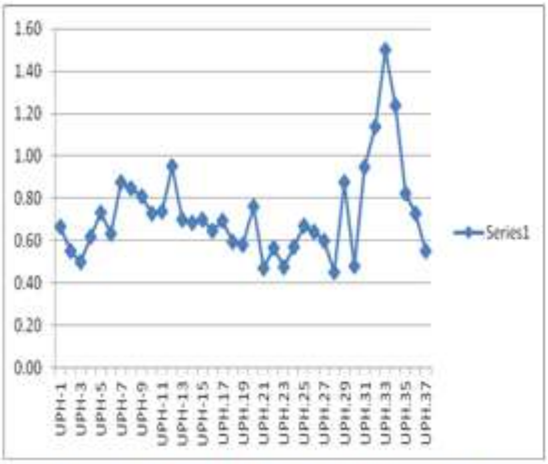

Figure 8b: Plot of Depth vs Uphole Points

6. Conclusion

This study has analyzed the weathering characteristics of the study area using the up-hole refraction survey method. The results from the up-hole refraction measurements show a two layer model in all the shot locations. The weathered layer thickness ranged from 3.1m around UPH-21 and 28 of the study area to 6.8m around UPH-12 and the average weathering thickness was determined to be about 4.7m. The average consolidated layer velocity was found to be 1707m sec^{-1}. This value falls within the range used for static correction on the reflection record as this removes its effect on the arrival time. The velocities of the weathered layers suggested that the weathered layers were relatively heterogeneous and loose. From the results obtained from this study, it isimperative that substantial static correction be done in the study area before any meaningful seismic reflection work can be carried out, owing to the high variations in weathered layer seismic velocity and thickness. The information obtained from this study is extremely important in the determination of the time delays needed for static corrections during seismic reflection data processing The determined depths to the base of the weathered layers are vital information required for the proper location of energy sources for noise(ground roll) reduction during acquisition of reflection/refraction data with the resultant effect of improving the signal to noise ratio (SNR) of seismic data. In most cases, locating the source below the weathered layer bypasses the layer thereby maximizing energy transmission.

7. Acknowledgement

The authors are indebted to BGP/CNPC for their role in the procurement of the up-hole geophysical data used for this study.

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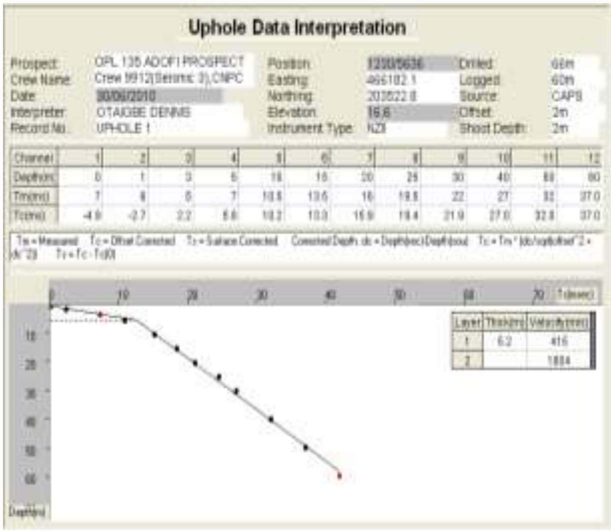
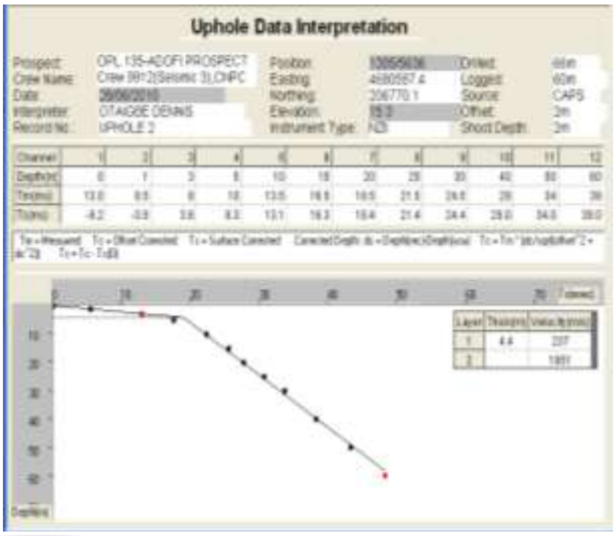
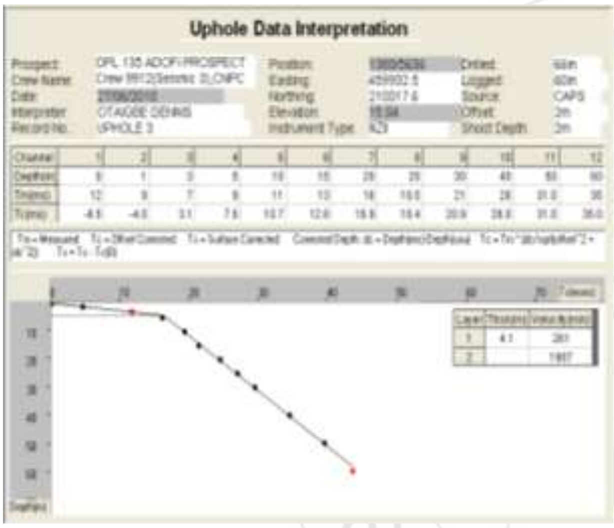
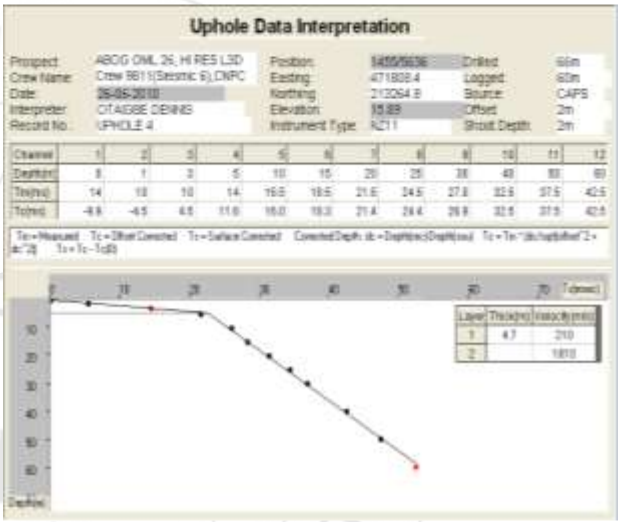
International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

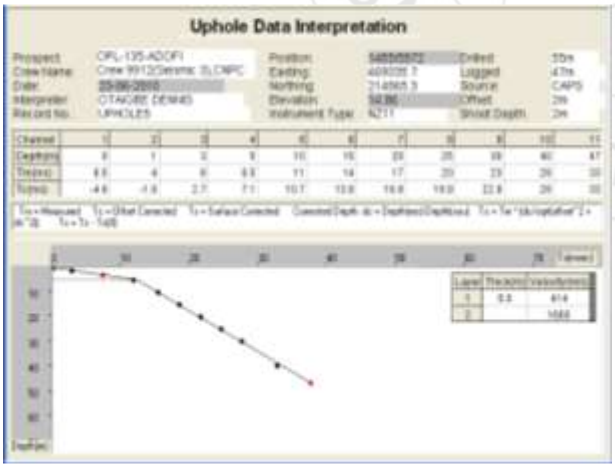
Results of some selected plots for study area

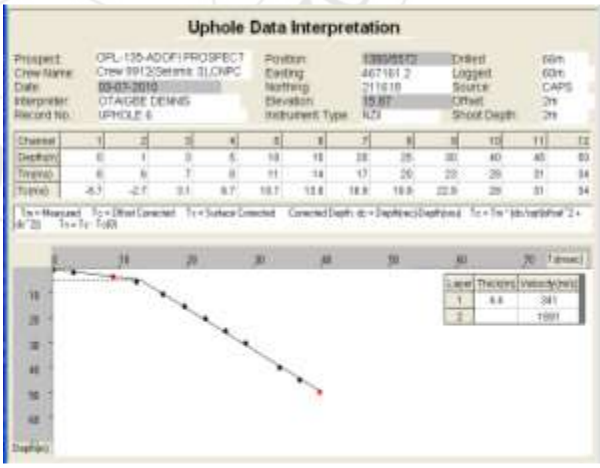












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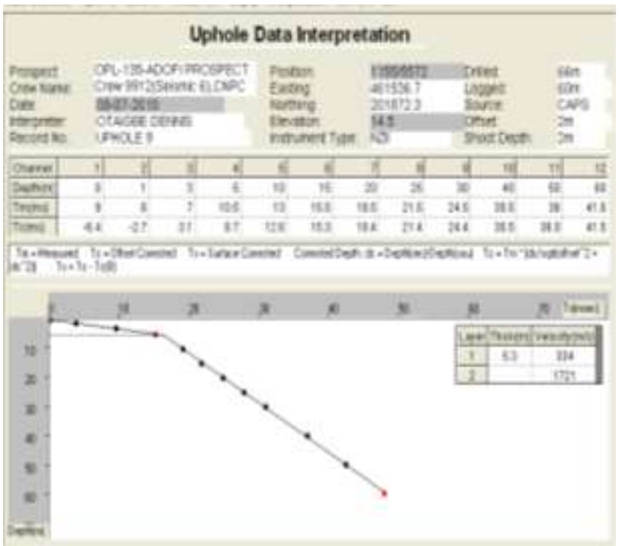

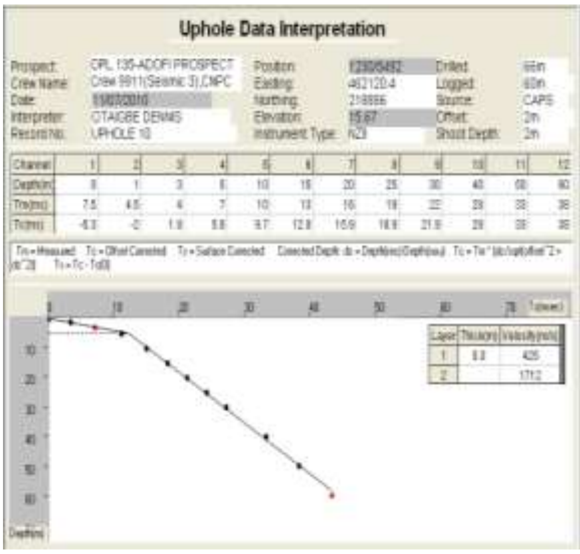

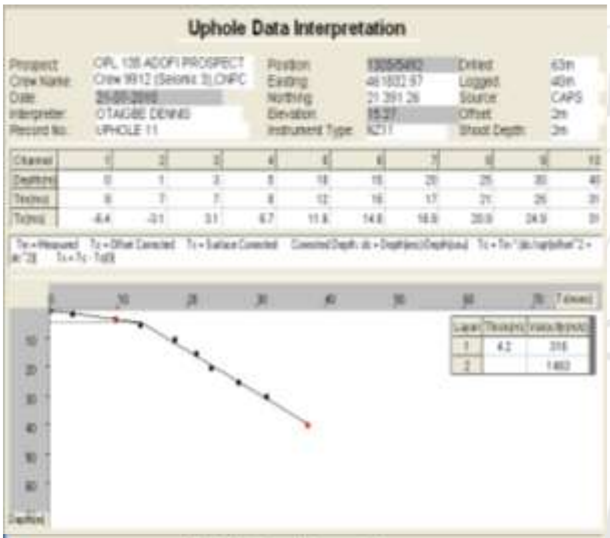

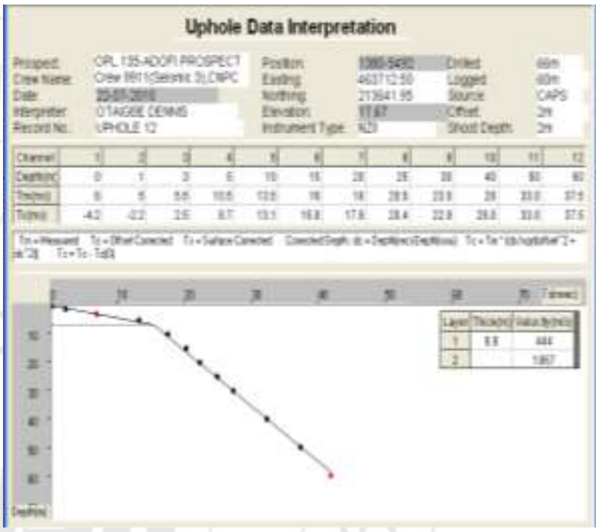

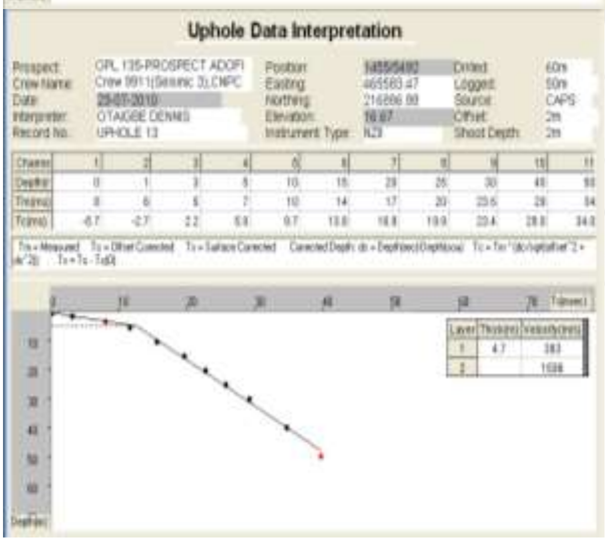

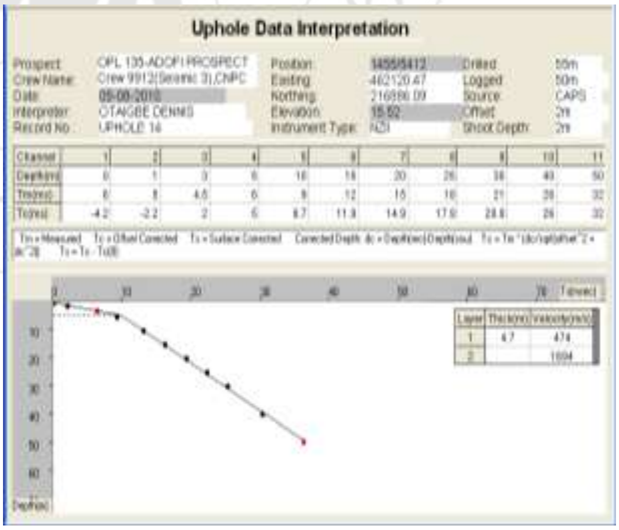

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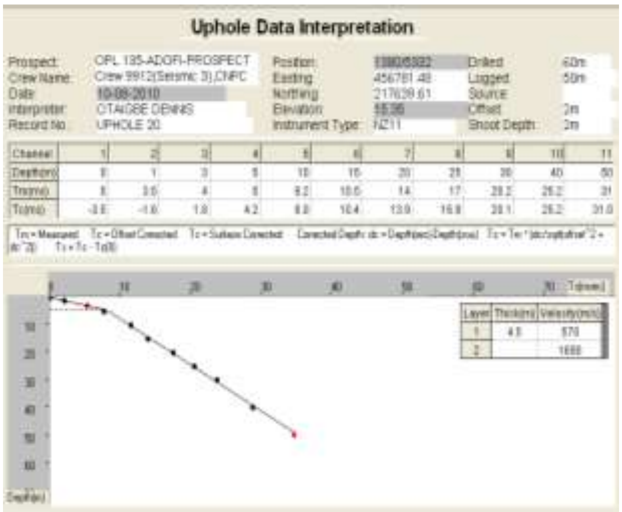

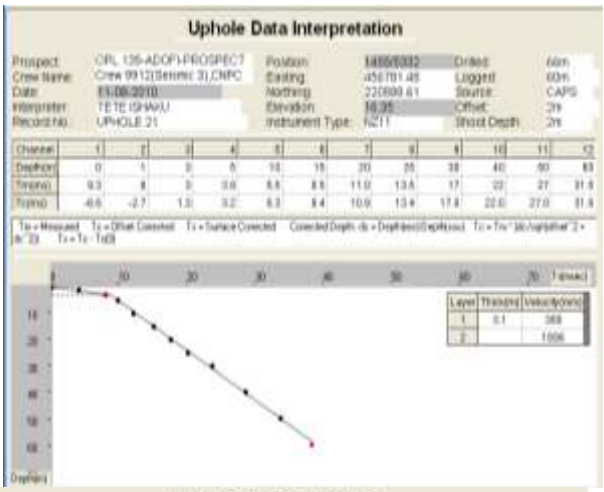

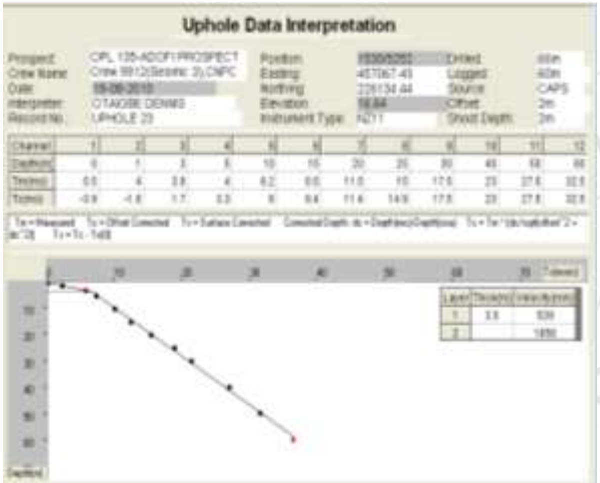

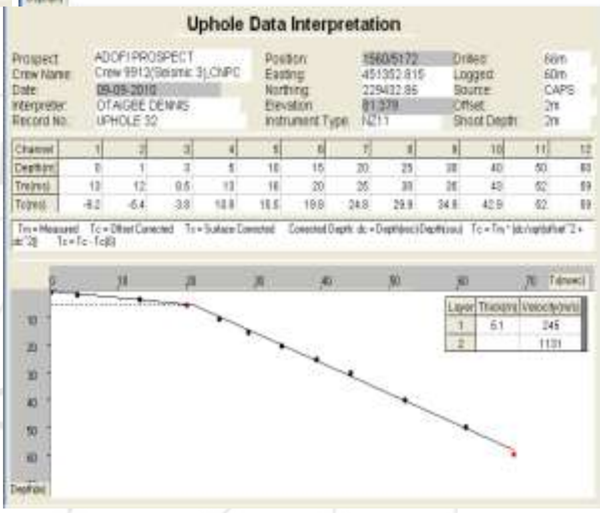

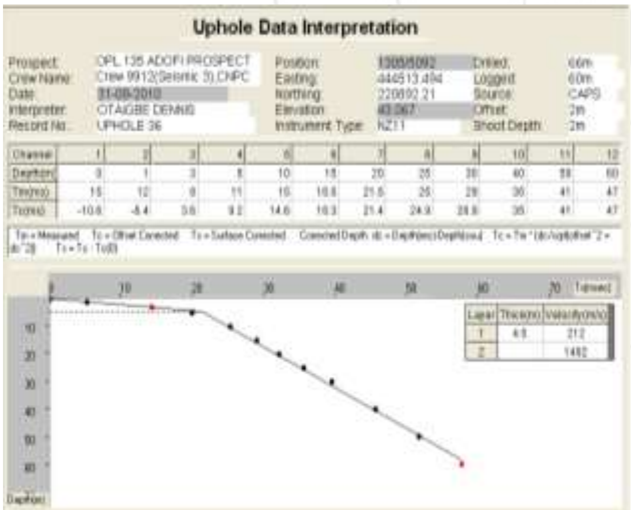

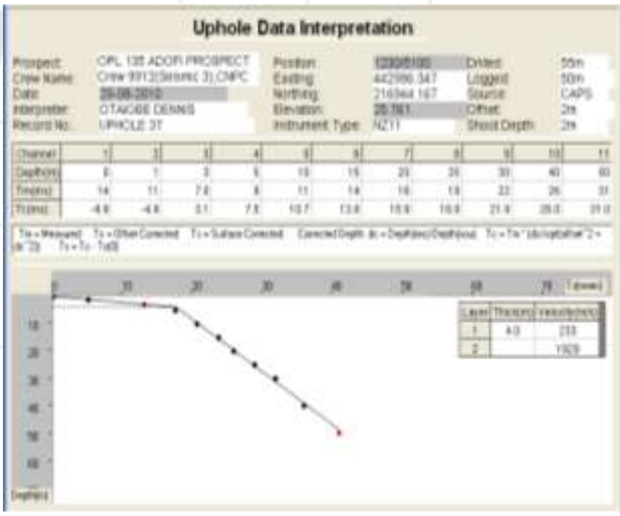

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